

# **Interactions of Small-Scale Physical Mixing Processes with the Structure, Morphology, Bloom Dynamics and Optics of Non-Spheroid Phytoplankton**

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## **LONG-TERM GOAL**

Our long-term goal is to understand the ecology of phytoplankton, especially the large, colonial diatoms which frequently dominate the flora of coastal shelves, upwelling areas, fjords and banks. We are interested in ways in which species-specific properties, including cell and colony size and shape interact with small-scale physical mixing processes to regulate the spatio-temporal distribution of diatoms. We wish to understand these processes in sufficient detail to be able to predict bloom dynamics, size structure and the impact of species-specific characteristics of the phytoplankton on ocean optics.

## **OBJECTIVES**

During FY2002, our objectives were: (1) to continue laboratory experiments designed to investigate the role that small-scale physical mixing processes operating on the scale of individual cells and colonies play in controlling patterns of phytoplankton distribution, and (2) to expand our knowledge regarding the existence, importance, and controlling mechanisms of thin layers of plankton in coastal ocean ecosystems via review of the published literature.

## **APPROACH**

*Laboratory experiments* focus on quantifying the role of small-scale turbulence in regulating colony size and morphology of planktonic diatoms. In order to further the development of our conceptual model, we are currently addressing several questions through a series of laboratory studies:

(1) Do diatoms alter size, shape and/or growth rate in response to the level of turbulence under which they are grown – is this ability common amongst the planktonic diatoms? (2) Does each species respond in a unique way? (3) Are the responses shape-specific – *i.e.* do different species belonging to a particular shape category respond to turbulence in a similar fashion?

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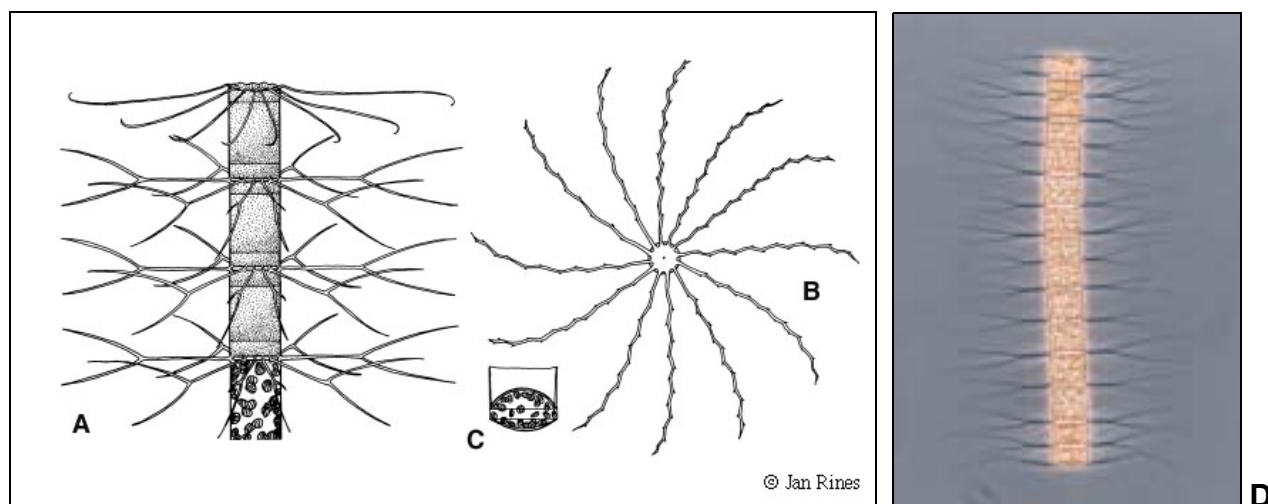
Clonal cultures were isolated from field samples shortly before experiments were conducted. Diatoms were grown in 5 levels of persistent small-scale turbulence (epsilon values from  $10^{-8}$  to  $10^{-3} \text{ m}^2 \text{ sec}^{-3}$ , quantified with a Sontec Acoustic Doppler Velocimeter), plus a quiescent control. We quantified growth rate (both as cell numbers, and as *in vivo* chlorophyll fluorescence measured with a WET Labs ECO-DFLS digital fluorometer), *in situ* particle length, and several morphological characters using light microscopy and image analysis. A WET Labs ac-9 was used to measure total and dissolved absorption and attenuation at 9 visible wavelengths. Water samples were  $0.2 \mu\text{m}$  filtered to measure dissolved absorption.

*Literature Review:* This effort is a direct outgrowth of the finding of our larger group of colleagues, and of our own research: Instrumentation developed by Donaghay, Holliday and Hanson has increased the spatio-temporal resolution of physical, optical, acoustical and biological field data, resulting in repeated documentation of a pattern of plankton distribution termed a ‘thin layer’. In order to determine how widespread thin layers are, we continue to examine, and if necessary reinterpret, the published phytoplankton, zooplankton and bioluminescence literature to look for studies that provide evidence of the existence of thin layers. Our objectives are to determine where in the world’s oceans thin layers have been reported, what taxa were present in the layers, and whether or not physical, optical, acoustical and/or chemical oceanographic data was concurrently collected.

*Imaging and cinematography:* State of the art microscopy and imaging is critical to both our laboratory and field work. We continue to develop hardware and software capabilities to enhance our research capabilities.

## WORK COMPLETED

*Laboratory experiments:* As part of our long-term efforts to investigate the effects of small-scale turbulence on diatoms of different shapes (e.g. helical, spiny, prismatic, needle-like, discoid, cylindrical, etc.), we conducted two new series of experiments. *Bacteriastrum hyalinum* was selected because the entire colony is fringed with hollow siliceous spines, or setae, such that the colony resembles a bottle brush (Figure 1). A complete colony occupies an ellipsoid volume.

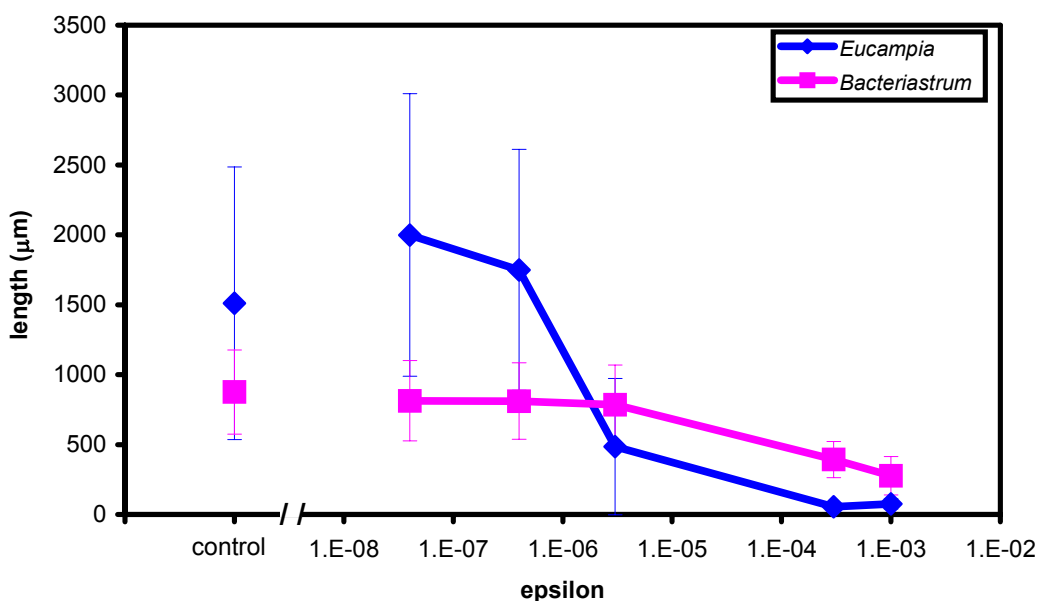


**Figure 1: Morphology of *Bacteriastrum hyalinum*. A, drawing of colony in girdle view, B, colony termination cell, viewed from end-on, D, photograph of living colony.**

*Chaetoceros debilis* is also spiny, but the entire colony is twisted into a helix, which may be very long – in East Sound, WA, we have observed colonies approximately 4 mm in length. Since we have already investigated the effects of small-scale turbulence on another helical diatom (*Eucampia zodiacus*, see last year’s report), our new results will allow us to ask if different helical taxa respond to turbulence in a similar fashion. This hierarchical information structure will provide insight on the role of shape in the ecology of planktonic diatoms. Three replicated experiments each were run on *B. hyalinum* and *Ch. debilis*. Data from the *B. hyalinum* experiments has been analyzed, but since we have just completed the *Ch. debilis* experiments, we do not yet have quantitative results for the latter taxon.

## RESULTS

**Laboratory experiments:** The length of *Bacteriastrum hyalinum* colonies decreased with increasing turbulence (Figure 2). However, this change was due not only to mechanical breakage of colonies into smaller fragments, but also to biological regulation of colony length. This diatom has extremely complex cell and colony morphology, including the formation of specialized, colony termination cells that lead to the division of each colony into two daughter colonies. Therefore, the number of cells per colony (and thus its overall length) is physiologically regulated. In our experiments, the number of cells per complete, intact colony decreased with increasing turbulence. Thus, two separate mechanisms – mechanical breakage and physiological regulation – influenced the particle size spectrum, and both were a function of the level of turbulence. Additionally, the length of the setae, and thus the overall width of the colonies decreased slightly with increasing turbulence.



**Figure 2: Comparison of mean colony length of *Bacteriastrum* and *Eucampia*, for each turbulence treatment, plus control. Bars = 1 standard deviation**

In contrast to the helical taxa *Eucampia zodiacus* (see last year’s report) and *Chaetoceros debilis* (below), *B. hyalinum* colonies from the unstirred control treatment were morphologically normal. *B. hyalinum* and *E. zodiacus* had different responses to turbulence (Figure 2). Between the lowest and

highest treatments, the mean length of *E. zodiacus* colonies decreased by 96%, whereas the mean length of *B. hyalinum* colonies decreased by 66%. At the highest levels of turbulence, only single cells and pairs of *E. zodiacus* cells were found, whereas *B. hyalinum* still formed colonies. Note that in contrast to *E. zodiacus*, the mean colony length of *B. hyalinum* remained essentially the same over the lower ranges of turbulence, decreasing only at high levels. The three-dimensional setae array of *B. hyalinum* may serve to “anchor” the colony in an ellipsoid of water, such that it “tumbles” in turbulence, and is less susceptible to shearing forces.

The *Chaetoceros debilis* data has not yet been analyzed, but we can make several qualitative observations. First, the length of the colony is dependent on the level of turbulence under which it has been grown. The longest colonies appear to form under low levels of turbulence; their morphology is representative of wild material. At high levels of turbulence, only short pieces of colonies are seen, and they are frequently tangled into macroscopically visible aggregates (*i.e.* marine snow). When stained with Alcian Blue and examined under the microscope, large amounts of extracellular polysaccharide can be visualized within the aggregate matrix. In the unstirred control, colony formation is abnormal, indicating that some turbulence is necessary to produce normal morphology.

*Literature review:* The following map (Figure 3) depicts locations where thin layers have been reported, based on the published literature. Unpublished reports from ONR, and NOPP-funded field work of Holliday, Donaghay and others are not currently incorporated, but will be added in the future.



**Figure 3: Reports of Thin Layers from the published literature.**

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Two points are immediately obvious: (1) Thin layers are a widespread phenomenon, found in many different kinds of environments, and (2), layers are most frequently reported where investigators have specifically examined fine-scale water column structure. Many areas of the ocean, especially in the

southern hemisphere, are under-represented because few relevant studies have taken place in these regions, and/or because data was not collected at the scales necessary to resolve layered structures.

## IMPACT/APPLICATIONS

Most conceptual and numerical models that attempt to predict the distribution of phytoplankton in space and time are carbon flow models. They are based on relationships between cell size and nutrient uptake kinetics, light harvesting efficiency, growth rates, sinking rates and grazing losses, all operating within the framework of average, large-scale seasonal stratification/destratification of the water column. Species-specific properties of phytoplankton – such as shape – are rarely considered. Our work has shown that interactions between small-scale mixing properties, and the size and shape of diatoms influence the size spectrum of particles. This has potential implications for marine food chains, and for ocean optics. Even more interesting is that at least some diatoms can acclimate to growth under persistent turbulence, by modifying their shape. This information can be placed within the context of the effect of regional scale physical processes in controlling the four-dimensional distribution of populations of phytoplankton, resulting in a variety of patterns, including thin layers.

## RELATED PROJECTS

The field portion of this project is most closely linked to the work of D. Van Holliday, because in collaboration with Donaghay's program, we compare the distributional patterns of zooplankton (as determined by acoustics) and phytoplankton (as determined by optics, and by microscopy) to each other, and to the physical structure of the water column. M. McManus' studies of circulation provide an important context for the interpretation of our data.

Instrumentation acquired under DURIP funding (N000149910598) has increased our research capabilities, and has provided additional opportunities. This past summer, Bowdoin undergraduate student Emily Grason, and her GSO mentor Dr. Lucie Maranda used our microscopy and imaging equipment to conduct research on the potentially toxic dinoflagellate *Dinophysis acuminata*. Rines is continuing to work on video productions of microscopic life in the sea, to be used for educational purposes. Under supplementary funding from ONR, a talk utilizing this material was given at the University of California at Santa Cruz, and at MBARI. This trip also provided an opportunity to spend a day on Monterey Bay aboard R/V *Point Lobos* with Drs. Bruce Robison and Larry Madin (WHOI), and observe ROV *Ventana* collecting mid-water salps.

## PUBLICATIONS

pdf versions of these publications, as well as abstracts of those recently submitted, can be found on my web site: <http://thalassa.gso.uri.edu/rines/pubs/publist.htm>

**Rines, J.E.B.**, P.L. Donaghay, M.M. Dekshenieks, J.M. Sullivan and M.S. Twardowski (2002) - Thin Layers and Camouflage: Hidden Pseudo-nitzschia populations in a fjord in the San Juan Islands, Washington, USA. Marine Ecology Progress Series 225: 123-137.

Allredge, A.L., T.J. Cowles, S. MacIntyre, **J.E.B. Rines**, P.L. Donaghay, C.F. Greenlaw, D.V. Holliday, M.M. Dekshenieks, J.M. Sullivan & R. Zaneveld. (2002) - Occurrence and mechanism of formation of a dramatic thin layer of marine snow in a shallow Pacific fjord. Marine Ecology Progress Series 233: 1-12.



Dekshenieks, M.M., P.L. Donaghay, J.M. Sullivan, **J.E.B. Rines**, T.R. Osborn and M.S. Twardowski. (2001) - Temporal and Spatial Occurrence of thin phytoplankton layers in relation to physical processes. Marine Ecology Progress Series 223: 61-71.

Dekshenieks, MM, AL Alldredge, A Barnard, E Boss, J Case, TJ Cowles, PL Donaghay, LB Eisner, DJ Gifford, CF Greenlaw, C Herren, DV Holliday, D Johnson, S MacIntyre, D McGehee, TR Osborn, MJ Perry, R Pieper, **JEB Rines**, DC Smith, JM Sullivan, MK Talbot, MS Twardowski, A Weidemann and JR Zaneveld (submitted 6/14/02) - Characteristics, distribution and persistence of thin layers over a 48 hour period. Marine Ecology Progress Series.

**Rines, J.E.B.**, P.L. Donaghay & J. Lemire (2002) – The effect of small-scale turbulence on the morphology and growth rate of *Eucampia zodiacus* Ehrenberg (Bacillariophyceae). Eos Trans. AGU 83 (4): Abstract OS42F-160.

Donaghay, P.L., D.V. Holliday, **J.E.B. Rines**, J.M. Sullivan, C.F. Greenlaw, D.E. McGehee, J. Miksis, M.M. Dekshenieks. (2002) – Challenges in sampling plankton structure and composition at critical scales in the coastal ocean. Eos Trans. AGU 83 (4): Abstract OS12A-132.